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GB05/367



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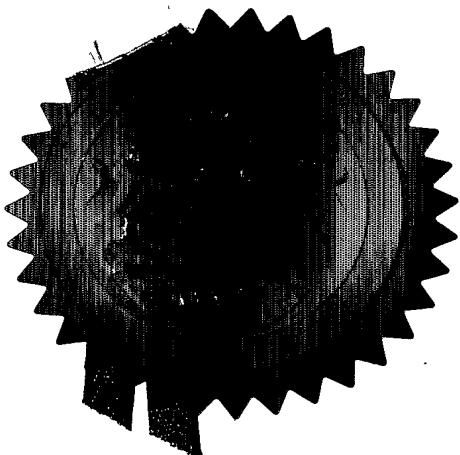
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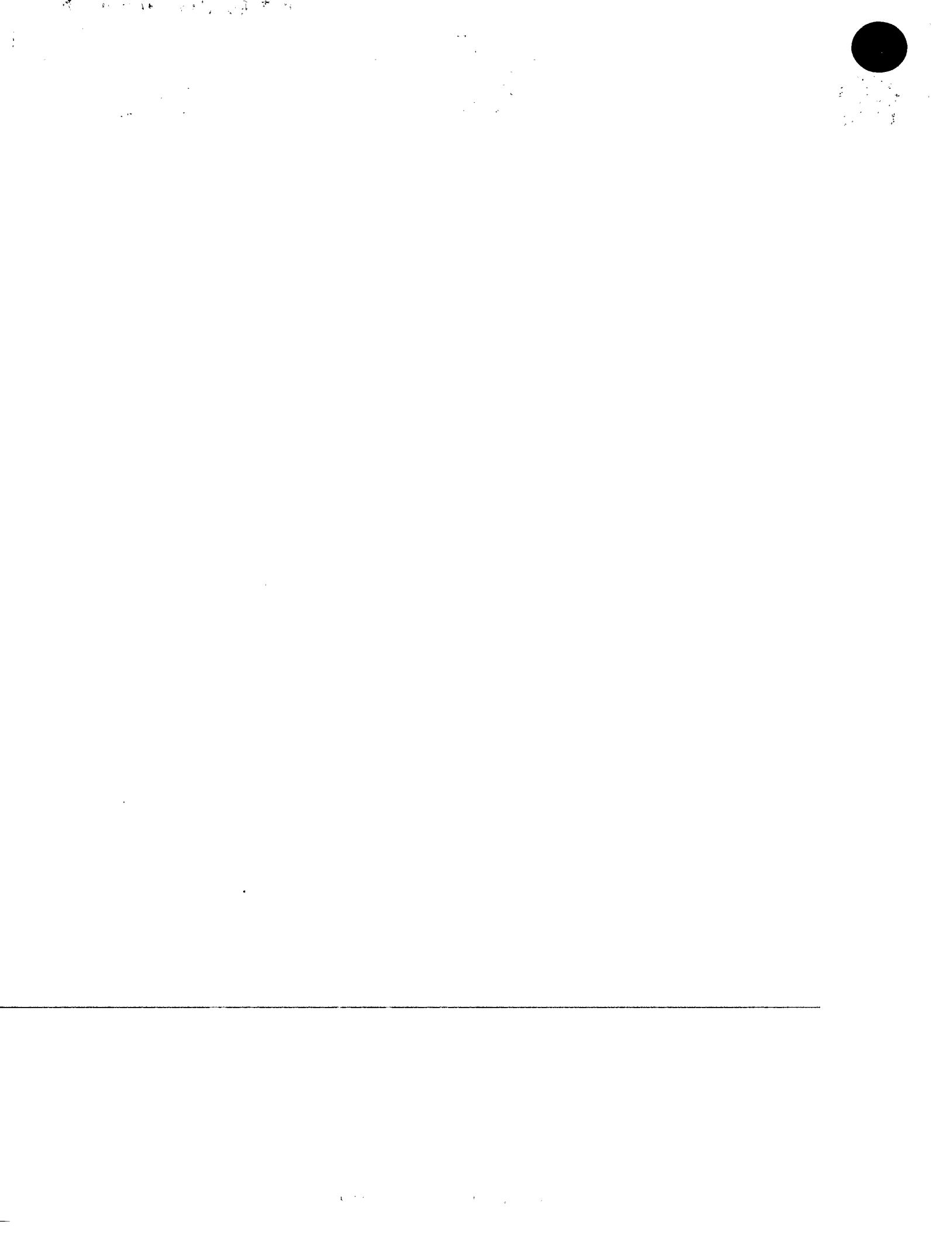
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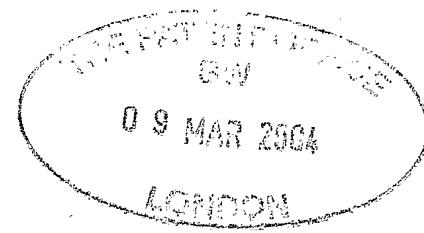
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The  
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Request for grant of a patent

The Patent Office

Cardiff Road  
Newport  
South Wales NP10 8QQ

1. Your reference

1909501/AM

2. Patent Application Number

0405312.0

09 MAR 2004

3. Full name, address and postcode of the or of each applicant (*underline all surnames*)

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Harston Mill  
Harston  
Cambridgeshire  
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8606275601

Patents ADP number (*if known*)

If the applicant is a corporate body, give the  
country/state of its incorporation

Country: ENGLAND  
State:

4. Title of the invention

GAS SENSOR

5. Name of agent  
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slm  
9.3.05

Patents ADP number

61004

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applications filed in the last 12 months.

Country

Priority application number

Date of filing

**Patents Form 1/77**

7. **Divisionals, etc:** Complete this section only if this application is a divisional application or resulted from an entitlement dispute.

#### Number of earlier application

Date of filing

8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?

YES

9. Enter the number of sheets for any of the following items you are filing with this form.

Continuation sheets of this form

### Description

5

**Claim(s)**

## Abstract

10. If  $\mathbf{S}^1$  is a  $\mathbf{S}^1$  in  $\mathbf{S}^1$ , then  $\mathbf{S}^1$  is a  $\mathbf{S}^1$  in  $\mathbf{S}^1$ .

Statement of inventorship and  
right to grant of a patent (Patent No. 7,777)

1 ± 3 COPIES

Request for preliminary examination and search (Patents Form 9/77)

Request for Substantive Examination  
(Patents Form 10/77)

Any other documents  
(please specify)

11. I/We request the grant of a patent on the basis of this application

Signature:

8 weeks for

BERESFORD & CO.

Date 9 March 2004

12. Name and daytime telephone number of person to contact in the United Kingdom

A. MACDOUGALL

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## Gas Sensor

*Peter Laitenberger, Gavin Troughton, Stuart Hendry*

### **Introduction**

Sensors for the concentration of a particular gas rely on one or more of a number of physico-chemical properties of the gas, ranging from chemical reactivity to thermal conductivity. In practical applications gas sensors are frequently used in uncontrolled environments. They may be exposed to a wide range of conditions that may affect their functioning, for example ambient temperature, humidity, pressure and the presence of cross interfering species.

For example, one distinct family of sensor types is that of electrochemical sensors, comprising of amperometric sensors, potentiometric sensors and conductimetric sensors. These are all characterised by having two or more electrodes in contact with a common electrolyte or ion conductor. In amperometric sensors, the target gas or a product of the target gas reacts at the sensing electrode and the gas concentration is inferred from the resultant current. In potentiometric sensors, the target gas or product of the target gas causes an electrical potential to build at the sensing electrode, which is measured to infer the gas concentration. In a conductimetric sensor, the effect of the target gas on the conductivity of the electrolyte is measured to infer gas concentration.

Electrochemical gas sensors are widely used for the measurement of the concentration of various gases. The advantages of electrochemical sensors are that they are generally relatively cheap to manufacture, have low power consumption and give an electronic response that is relatively simple to integrate into low cost electronics.

One of the main disadvantages of electrochemical gas sensors is that the sensitivity and response of the sensor can be strongly affected by changes in the physical environment that it is within. Quite specifically, the electrolytes used in many electrochemical sensors contain a concentration of water that will equilibrate with the water concentration in the ambient gas in which the sensor is placed. In low ambient humidity the electrolyte will therefore lose water, with the converse being true in high humidity. This change in water concentration can significantly affect the accuracy of the sensor. The consequences of these changes are that the sensor may need frequent calibration, does not have the accuracy for a specific application or may only be stored and used in limited environmental conditions.

Historically, many electrochemical sensors have used liquid electrolytes, for example ionic species dissolved in water or another solvent. While these can give excellent performance, keeping a corrosive liquid electrolyte inside a sensor while allowing gas to freely pass in and out has proved a significant challenge and in many cases sensors have proved highly unreliable. The use of solid electrolytes, either gel based (such as hydrogels of electrolytes) or conducting polymers (such as Nafion®), is therefore highly attractive. However, the properties of these electrolytes are typically much more sensitive to humidity than those of liquid electrolytes. Humidification of the electrolyte

may be achieved by the addition of a water reservoir<sup>1</sup>, but this reinstates many of the encapsulation issues experienced with liquid electrolytes.

Similar issues exist for all other types of gas sensors based on other transduction principles.

### **The Invention**

The concept of the invention is a device that combines a gas sensor with one or more condition monitoring sensors to correct for environmental or ageing effects on the gas sensor performance. The sensors for gas measurement and condition monitoring may be operated in either a continuous or intermittent mode.

The principle of the gas sensor could be amperometric, potentiometric, conductimetric, gravimetric, thermal, resonant surface acoustic wave, optical or others known to those skilled in the art.

The condition monitoring sensors could measure temperature, atmospheric pressure, electrolyte conductivity or composition, capacitance, mass, optical properties, stress, strain, force or dimensions.

The device has the associated electronics to drive the various sensors and to output a condition corrected electronic signal dependent on the concentration of target gas present. The correction may be through algorithms, look-up tables or another method.

One example embodiment is a potentiometric acid gas sensor with a solid electrolyte. The gas sensor comprises a pH sensitive ISFET microsensor covered with a layer of solid, gel or liquid electrolyte under a gas diffusion membrane. Diffusion of an acid or alkaline gas, such as carbon dioxide or sulphur dioxide or ammonia, through the gas diffusion membrane and into the electrolyte will lead to a change in pH of the electrolyte and a consequent change of signal at the ISFET sensor. There are at least two additional electrodes in contact with the electrolyte which are used to monitor the electrical response of the electrolyte layer to an imposed voltage. A diagram of the configuration of the sensor is shown in Figure 1. The silicon chip may include an integral temperature sensor (not shown in the diagram), or a separate temperature sensor may be used.

The monitoring of the electrolyte layer may be carried out by applying either a constant, stepped or modulated voltage. A modulated voltage may be applied at a single frequency or a number of different frequencies. The resulting current or phase change may be measured to infer the condition of the electrolyte arising from changes in either or both of the resistive and capacitative response of the condition monitoring circuit.

The sensor may optionally incorporate a chemical or physical filter element to reduce sensitivity of the sensor to a cross-interfering species. For example this may be a layer

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<sup>1</sup> See e.g. EP0762117B1

of activated charcoal cloth, chemical impregnated carbon cloth or other chemical impregnated materials, known to those skilled in the art.

The device also includes the electronics to drive and monitor signals from the temperature, electrolyte monitoring and potentiometric sensors. The signal from the gas sensor is corrected to take into account the effects of electrolyte condition and temperature and output an electronic signal dependent on the gas concentration.

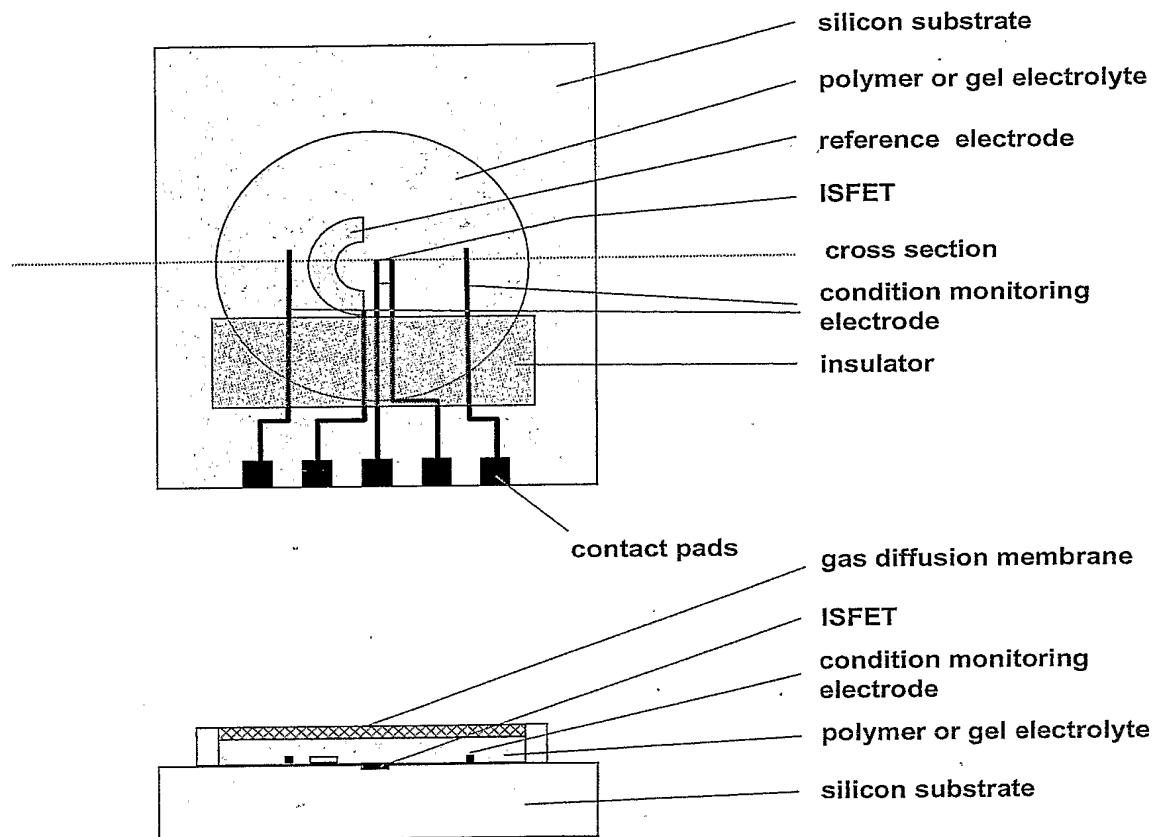
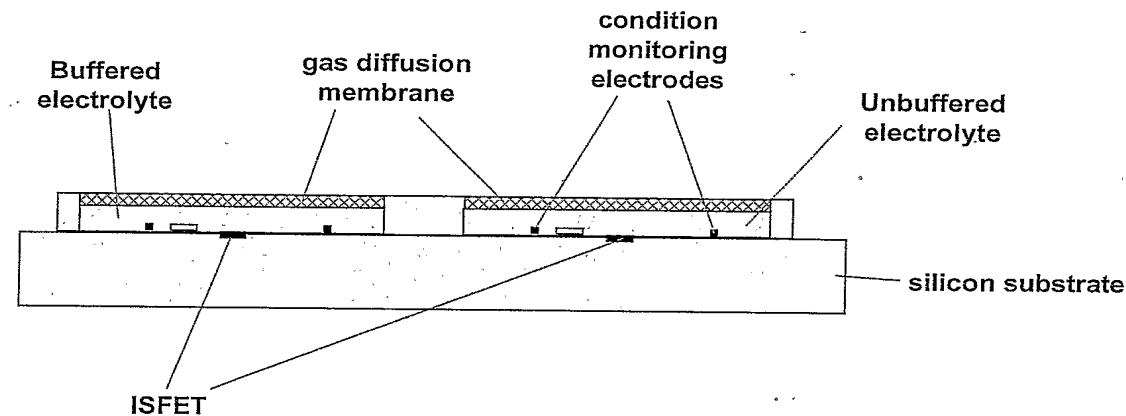


Figure 1: Plan and cross section diagrams of a sensor for the detection of acid or alkaline gases.

A second example embodiment (Figure 2) is a gas sensor system with two ISFET transducers, preferably on the same substrate configured to form a sensitive and reference pair of sensors. A layer of unbuffered electrolyte is deposited onto one ISFET transducer (sensitive sensor), which is then optionally covered with a gas diffusion layer. A similar construction is used on the second transducer (reference sensor), but in this case the electrolyte is buffered. The buffering capacity of the electrolyte is ideally sufficient to keep the pH of the electrolyte approximately constant in the working range of target gas concentration. In the simplest embodiment, the signal from the reference sensor may be subtracted from that of the sensitive element. However, more elaborate compensation schemes may be employed, known to those skilled in the art.

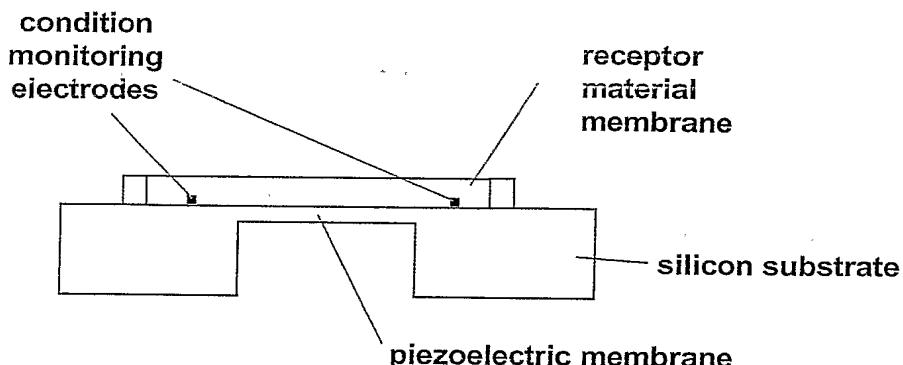
In addition to compensation by the reference sensor, the accuracy of the sensor over the full range of environmental conditions may be improved by the use of temperature and electrolyte condition monitoring sensing. The signal from these auxiliary measurements is used to compensate the signal from the chemical sensor as described in the embodiment above.



*Figure 2: Cross section diagram of a sensitive/non sensitive pair of sensors for acid gas detection.*

Further embodiments of the invention employ two or more sensors that employ permutations of electrolyte buffering, physical and chemical filtration.

A third example embodiment is that of a system for monitoring the concentration of, for example, propofol in the breath of a human or animal, referred to as a "patient". A surface acoustic wave device is modified with a layer of receptor material deposited onto the piezoelectric membrane (Figure 3). The receptor material preferentially binds or absorbs propofol, leading to a change in the mechanical properties of the piezoelectric membrane, which may be determined by time of flight measurements or other such methods known to those skilled in the art. The receptor material may be a molecularly imprinted polymer or other synthetic or naturally occurring receptor material. Preferably the receptor material is optimised to reversibly bind propofol so that the same sensor may be used for continuous measurement or to make a series of measurements.



*Figure 3: Cross section diagram of a sensor for propofol vapour.*

The stability and sensitivity of such a sensor is liable to depend on a number of factors including, ambient temperature, humidity and other breath borne species. One or more of the following auxiliary measurements is therefore carried out with a sensor preferably integrated on the same chip:

- The conductivity or capacitance of the receptor layer as described in the first embodiment
- An equivalent SAW device with no added layer
- An equivalent SAW device with a non-sensitive layer, for example a layer of the MIP polymer but without the specific binding sites.
- A temperature sensor

The device may also include the electronics to drive and monitor signals from all the sensors. The signal from the auxiliary sensor(s) is combined with the signal from the chemical sensor in a suitable manner and output as an electronic signal proportional to the gas concentration.

A sample of the patient's breath is passed over the sensor to make the measurement. This may be effected by placing the sensor directly into an endotrachael tube, anaesthetic circuit or ventilator circuit, or by drawing a sample from such a site into a gas flow housing containing the sensor. The reading from the device may be displayed on a monitor, input (potentially with other patient data) into an expert system to advise clinical staff on control of anaesthesia or alternatively used for closed-loop control of anaesthesia.

Possible variants on this embodiment include any combination of the following approaches:

- Use of a receptor layer specific for a volatile product of the metabolic breakdown of propofol that may be quantitatively linked to blood propofol concentration.
- Use of other transduction principles including electrochemical and optical transducers.
- Use of a receptor layer for another target drug, metabolyte or other species in the breath to infer a concentration in the blood.

